

# Late Cretaceous (late Campanian-early Maastrichtian) radiolarian biogeography; a review

Osamu TAKAHASHI

Department of Astronomy and Earth Sciences, Tokyo Gakugei University,  
Koganei-shi, Tokyo 184-8501 (Japan)  
takahasi@u-gakugei.ac.jp

---

Takahashi O. 1999. — Late Cretaceous (late Campanian-early Maastrichtian) radiolarian biogeography; a review, in De Wever P. & Caulet J.-P. (eds), InterRad VIII, Paris/Bierville 8-13 septembre 1997, *Geodiversitas* 21 (4) : 739-750.

## ABSTRACT

Some characteristic species of Late Cretaceous radiolarians from central Japan and the world are discussed. With respect to the relation between radiolarian distribution and latitude, *Amphipyndax enesseffi* Foreman, *Theocampe abschnitta* (Empson-Morin), *Mylocercion acineton* Foreman, and *Dictyomitra lamellicostata* Foreman were restricted to the low to intermediate latitudes. *Lithomelissa heros* Campbell & Clark, *Lithomelissa hoplites* Foreman, *Theocampe altamontensis* (Campbell & Clark), and *Stichomitra livermorensis* (Campbell & Clark) would tend to be cosmopolitan; however, only in the circum-Pacific region, they were apparently confined to northeastern Asia, northwestern North America, and the Antarctic. The existence of the distribution of the Late Cretaceous radiolarians could be explained by oceanic circulation patterns and it was important in determining Late Cretaceous provincial boundaries of radiolarians.

## KEY WORDS

Late Cretaceous,  
radiolarians,  
Tethys,  
Atlantic,  
Pacific,  
oceanic circulation.

## RÉSUMÉ

*Biogéographie des radiolaires du Crétacé supérieur (Campanien supérieur-Maastrichtien inférieur) : bilan.*

Quelques espèces caractéristiques du Crétacé supérieur du Japon central et du monde sont discutées. Tenant compte des distributions paléolatitudinales, il apparaît que *Amphipyndax enesseffi* Foreman, *Theocampe abschnitta* (Empson-Morin), *Mylocercion acineton* Foreman, and *Dirtyomitra lamellicostata* Foreman sont restreints aux basses latitudes ou intermédiaires, alors que *Lithomelissa heros* Campbell & Clark, *Lithomelissa hoplites* Foreman, *Theocampe altamontensis* (Campbell & Clark), and *Stichomitra livermorensis* (Campbell & Clark) tendraient à être cosmopolites. Néanmoins, dans les régions circum-Pacifique, ils sont apparemment confinés au Nord-Est de l'Asie, au nord-ouest de l'Amérique du Nord et à l'Antarctique. L'existence de cette distribution au Crétacé supérieur pourrait être expliquée par des courants océaniques qui ont déterminé les limites des provinces fauniques de radiolaires à cette époque.

## MOTS CLÉS

Crétacé supérieur,  
radiolaires,  
mer mésogéenne,  
Atlantique,  
Pacifique,  
circulation océanique.

## INTRODUCTION

Radiolaria are effective indicators of various oceanic environments: paleoceanographic, paleoecologic, bathymetric, etc. Since Haeckel (1887), many paleobiogeographic studies of radiolarians have been done during the past 100 years. However, most have been restricted to the Cenozoic (e.g., Casey 1971; Goll & Björklund 1971; Petrushevskaya 1971), and very little has been published on radiolarian paleobiogeography from the Mesozoic. Pessagno (1976) established a radiolarian zonation for the Upper Cretaceous portion of the Great Valley sequence of Northern California and stated that radiolarian species common to the Upper Cretaceous strata of the Tethyan, Boreal, and Austral Faunal Provinces are eurybathic and would tend to be more cosmopolitan. However, commencing with the study of Empson-Morin (1984), Upper Cretaceous radiolarians have been appreciated as valuable biogeographic tools. She described the Upper Cretaceous radiolarians as effective environmental indicators showing variations in response to depth and/or latitude.

Recently, a preliminary study by Takahashi & Ishii (1993) stated that the Upper Cretaceous (late Campanian-early Maastrichtian) strata of central Japan include two characteristic radiolarian faunas. I have noticed in the Late Creta-

ceous Northwestern Pacific Ocean an example showing two parallel distributions of characteristic radiolarian faunas; the similarity of the northern Northwestern Pacific fauna and the lack of similarity of the southern Northwestern Pacific fauna to species of the California Upper Cretaceous (e.g., Campbell & Clark 1944).

## LATE CAMPANIAN TO EARLY MAASTRICHTIAN RADIOLARIANS FROM CENTRAL JAPAN

### GEOLOGIC SETTING AND RADIOLARIAN FOSSILS OF THE SHOYA FORMATION, NORTHERN CENTRAL JAPAN

The Shoya Formation (Watanabe 1958) is exposed in an area approximately 0.5 km wide and 4.5 km long, and located 100 km northwest of Tokyo (Fig. 1). It consists of three lining-upward cyclic sequences of marine sedimentary rocks about 600 m in total thickness, lacking pelagic interbeds. The lower and middle parts of each sequence are composed of poorly-sorted, black, medium- or fine-grained sandstone, which grade upward into well-sorted, bedded, dark gray sandstone. The upper part of each sequence is composed of alternations of mudstone and sandstone with dark gray, siliceous mudstone. The siliceous mudstone frequently contains thin (several milli-

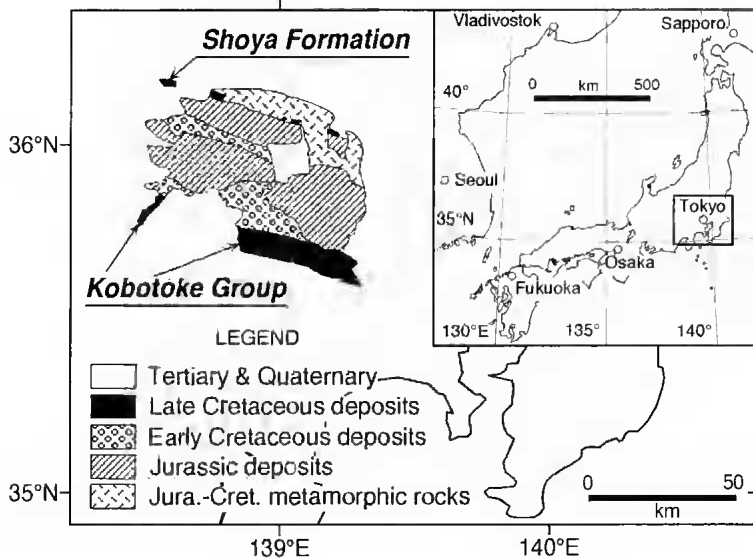


FIG. 1. — Index map of the study area showing the position of the Shoya Formation and the Kobotoke Group in central Japan.

meters) layers of interbedded, greenish-gray, tuffaceous mudstone or tuff. Some sandstone units contain abundant, yet poorly preserved molluscs, including *Spondylus japonicus*, *Cardium*(?), *Ostrea*, other pelecypods, brachiopods, and corals (Amano & Marui 1958). Based on tectonic configuration, litho- and bio-facies, the Shoya Formation is interpreted as a typical forearc sequence at the eastern margin of the Asian Continent (Ishii & Takahashi 1993).

Radiolarian fossils were encountered in the dark gray or black siliceous mudstone parts of the strata. The radiolarian assemblage contains 17 species belonging to 10 genera (Table 1), some of which are shown in Fig. 2A-S. The assemblage rarely contained *Amphipyndax tylotus* Foreman and *A. enesseffi* Foreman, and is characterized by the occurrence of *Lithomelissa heros* Campbell & Clark, *L. hoplites* Foreman, *Theocampe altamontensis* (Campbell & Clark), and *Stichomitra livermorensis* (Campbell & Clark).

#### GEOLOGIC SETTING AND RADIOLARIAN FOSSILS OF THE KOBOTOKE GROUP, SOUTHERN CENTRAL JAPAN

The Kobotoke Group (Makino 1973; Sakai 1987) is exposed in an area approximately 10 km wide and 70 km long, and located 50-100 km

west of Tokyo (Fig. 1). It is composed of rhythmically alternating beds (several centimeters thick) of fine- to medium-grained arkosic sandstone and black mudstone, occasionally including chert and limestone blocks and conglomerate lenses in the mudstone dominant part. The chert is mostly red and rhythmically bedded and the limestone is dark gray in color. The conglomerate is composed of pebbles of limestone, chert, sandstone, and mudstone within a sandy matrix, and they are found in small bodies sporadically scattered in the sandstone layers.

The strata show normal graded bedding and are steeply dipping northward in a monoclinical structure, nevertheless, the geological ages of the southern beds are younger than those of the northern beds (Ishii *et al.* 1990). These features, the overall younging towards the south by repetition of the strata within imbricate thrusts, suggest a typical strata distribution for an accretionary prism (Ishii & Takahashi 1993).

Radiolarian fossils were encountered in the siliceous, dark gray or black mudstone parts of the strata. The radiolarian assemblage contains 11 species belonging to 6 genera (Table 1), some of which are shown in Fig. 3A-M. The assemblage is characterized by the predominant occurrence of *Amphipyndax tylotus* Foreman and

TABLE 1. — Occurrence and relative abundance of radiolarians of the Shoya Formation and the Kobotoke Group. Radiolarian abundances are categorized as common (C) and rare (R). Plus (+) means presence, but recognized with such difficulty that no estimate of abundance could be made.

Taxon	Shoya Formation					Kobotoke G.	
	Sh-1	Sh-2	Sh-3	Sh-4	Sh-5	St-1	St-2
<i>Amphipyndax alamedaensis</i> (Campbell & Clark)	—	C	—	—	—	R	R
<i>A. enesseffi</i> Foreman	R	—	—	R	—	C	R
<i>A. plousios</i> Foreman	—	C	—	R	—	—	—
<i>A. stocki</i> (Campbell & Clark)	C	C	+	C	+	C	C
<i>A. tylotus</i> Foreman	—	C	+	C	—	C	C
<i>Archaeospongoprimum salumi</i> Pessagno	C	—	—	C	—	—	—
<i>A. stocktonensis</i> Pessagno	—	—	—	R	—	—	—
<i>Cornutella californica</i> Campbell & Clark	—	—	—	R	—	R	—
<i>Dictyomitra andersoni</i> (Campbell & Clark)	R	C	—	C	+	C	C
<i>D. lamellicostata</i> Foreman	—	—	—	—	—	C	C
<i>D. multicostata</i> Pessagno	C	C	+	C	—	C	C
<i>Eribotrys anax</i> Foreman	—	—	—	R	—	—	—
<i>Lithomelissa heros</i> Campbell & Clark	—	—	—	C	—	—	—
<i>L. hoplites</i> Foreman	—	—	—	C	+	—	—
<i>Myllocercion acineton</i> Foreman	—	—	—	—	—	C	—
<i>Praeconocaryomma dauerhafta</i> (Empson-Morin)	—	—	—	—	—	R	—
<i>Pseudoaulophacus floresensis</i> Pessagno	—	—	—	—	—	R	R
<i>Rhopalosyringium magnificum</i> Campbell & Clark	—	C	—	—	—	R	C
<i>Saturniforma brionesensis</i> Pessagno	—	—	—	C	—	—	—
sciadiocapsid	R	—	—	C	—	—	—
<i>Stichomitra asymbatos</i> Foreman	R	C	—	R	—	C	R
<i>S. livermorensis</i> (Campbell & Clark)	—	C	—	C	—	—	—
<i>Theocampe abschnitta</i> (Empson-Morin)	—	—	—	—	—	C	R
<i>T. altamontensis</i> (Campbell & Clark)	—	—	—	C	—	—	—
<i>Theocapsomma amphora</i> Campbell & Clark	R	C	—	C	—	—	—

*A. enesseffi* Foreman, and also characterized by the occurrence of *Theocampe abschnitta* (Empson-Morin), *Dictyomitra lamellicostata* Foreman, and *Myllocercion acineton* Foreman.

#### AGE ASSIGNMENT

The two radiolarian assemblages from the Shoya Formation and the Kobotoke Group have some differences in their components. However, these assemblages contain common and/or individual typical species of the *Amphipyndax tylotus* zone (Foreman 1977; Sanfilippo & Riedel 1985). For example, the first appearances of *Lithomelissa hoplites* and *Theocampe abschnitta* are included

near the base of the *A. tylotus* zone. The top of the zone is defined as the Maastrichtian/Danian boundary recognized by the last occurrences of *A. tylotus*, *L. hoplites*, and *Dictyomitra lamellicostata* (Foreman 1968, 1977; Sanfilippo & Riedel 1985). With respect to the other species, the first appearances of *Lithomelissa heros*, *Theocampe altamontensis*, and *Myllocercion acineton* are Campanian (Pessagno 1976; Foreman 1978; Taketani 1982; Empson-Morin 1981; Sanfilippo & Riedel 1985), whereas *Stichomitra livermorensis* first occurs in the Coniacian (Moore 1973). The final occurrences of these species also correspond to the top of the *A. tylotus* zone at the Maastrichtian/Danian boundary (Foreman 1968, 1978; Sanfilippo & Riedel 1985).

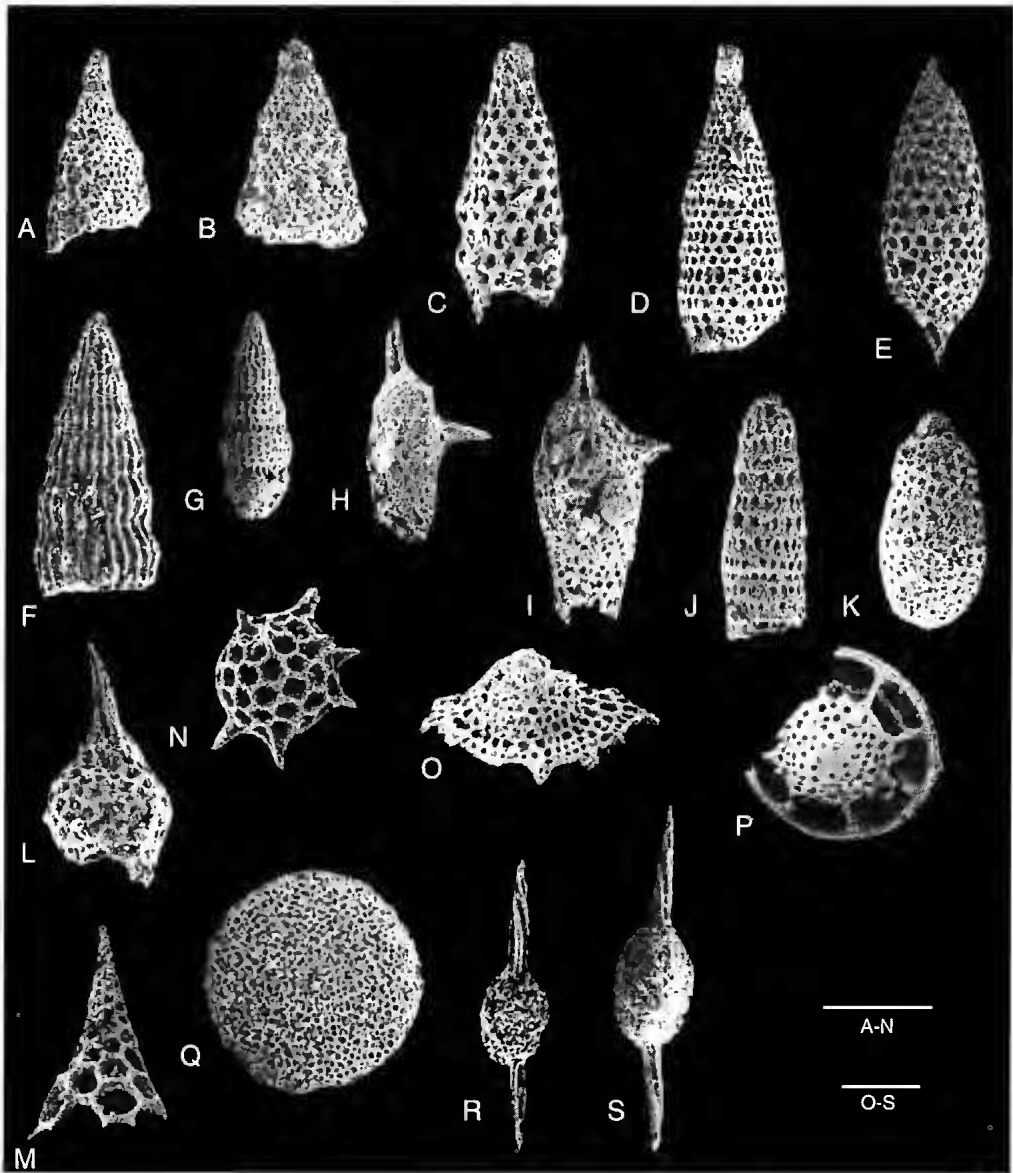


FIG. 2. — Late Campanian-early Maastrichtian radiolarian fauna from the Shoya Formation, northern central Japan. A, *Amphipyndax tylotus* Foreman; B, *Amphipyndax enesseffi* Foreman; C, *Amphipyndax alamedaensis* (Campbell & Clark); D, *Amphipyndax stocki* (Campbell & Clark); E, *Stichomitra livermorensis* (Campbell & Clark); F, *Dictyomitra multicostata* Pessagno; G, *Dictyomitra andersoni* (Campbell & Clark); H, *Lithomelissa heros* Campbell & Clark; I, *Lithomelissa hopties* Foreman; J, *Theocampe altamontensis* (Campbell & Clark); K, *Theocapsomma amphora* Campbell & Clark; L, *Rhopalosyringium magnificum* Campbell & Clark; M, *Cornutella californica* Campbell & Clark; N, gen. sp. indet.; O, Sciadocapsid gen. sp. indet.; P, *Saturniforma brionesensis* Pessagno; Q, *Orbiculiforma* sp.; R, *Archaeospongoprimum salumi* Pessagno; S, *Archaeospongoprimum stocktonensis* Pessagno. Scale bars: 0.1 mm

Therefore, these species of both assemblages recovered from the Shoya Formation and the Kobotoke Group represent the *Amphipyndax tylotus*

zone which is indicative of a range from the late Campanian to the early Maastrichtian in age (Foreman 1977, 1978; Sanfilippo & Riedel 1985).

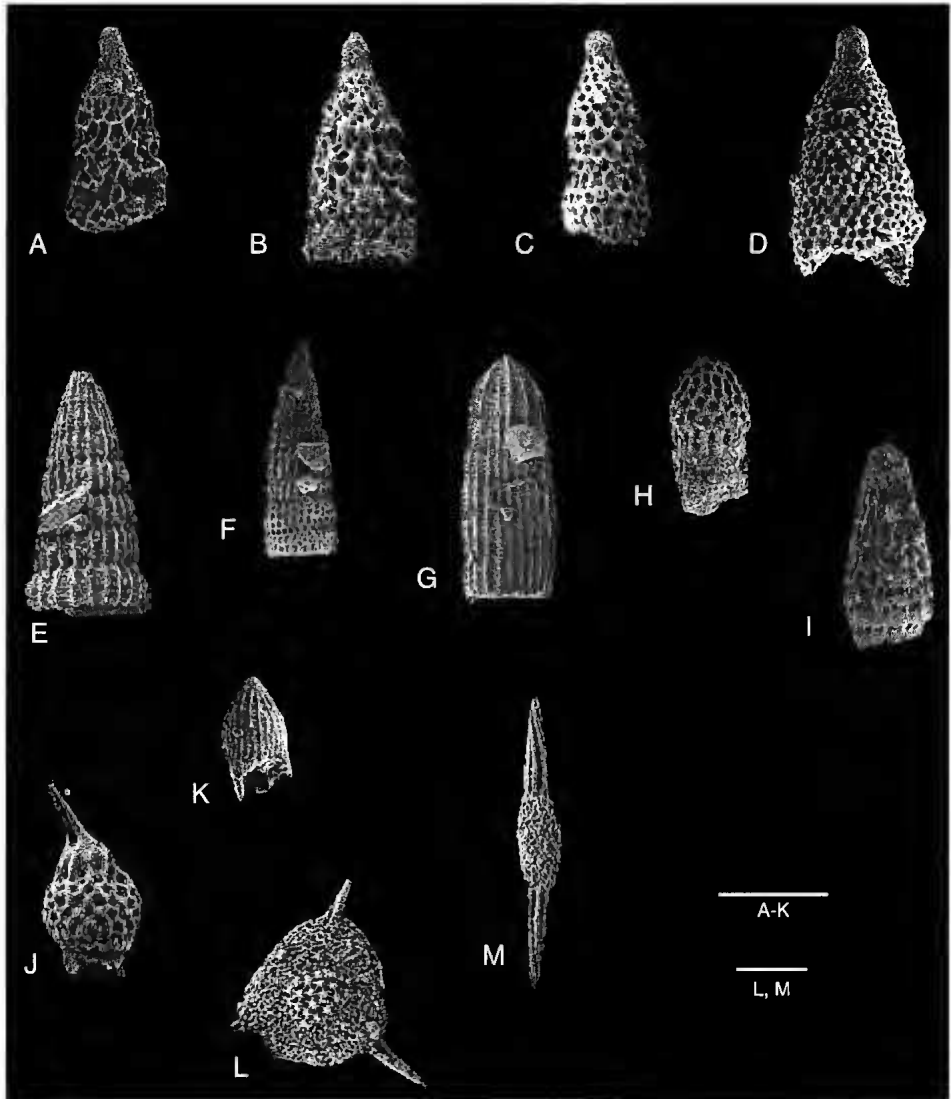


FIG. 3. — Late Campanian-early Maastrichtian radiolarian fauna from the Kobotoke Group, southern central Japan. **A**, *Amphipyndax tylotus* Foreman; **B**, *Amphipyndax enesseffi* Foreman; **C**, *Amphipyndax alamedaensis* (Campbell & Clark); **D**, *Amphipyndax stocki* (Campbell & Clark); **E**, *Dictyomitra mullicosulata* Pessagno; **F**, *Dictyomitra andersoni* (Campbell & Clark); **G**, *Dictyomitra lamellicostata* Foreman; **H**, *Theocampe abschnitta* (Empson-Morin); **I**, *Theocampe* sp.; **J**, *Rhopalosyringium magnificum* Campbell & Clark; **K**, *Mylocercion acineton* Foreman; **L**, *Pseudoaulophacus floresensis* Pessagno; **M**, *Archaeospongoprurum* sp. Scale bars: 0.1 mm.

#### PALEOBIOGEOGRAPHIC DISTRIBUTIONS OF LATE CAMPANIAN- EARLY MAASTRICHTIAN RADIOLARIANS

Selected pairings of the assemblages from the

Shoya Formation and the Kobotoke Group were compared by means of a similarity index (Jaccard Coefficient: Table 2). The results show that the pairings between the Kobotoke Group (St-1 and St-2) and the Shoya Formation (Sh-1, Sh-2, and

TABLE 2. — A matrix of similarity values (JI: Jaccard index) for comparisons of radiolarian assemblages from each sample.

	Shoya F.		Kobotobe G.	
	Sh-2	Sh-4	St-1	St-2
Sh-1	0.38	0.44	0.29	0.36
Sh-2		0.40	0.41	0.50
Sh-4			0.28	0.26
St-1				0.78

Sh-4) yielded somewhat lower values than did pairings from within each one. Namely, each assemblage is characterized by different species. For example, the assemblage from the Shoya Formation is characterized by the occurrence of *Lithomelissa heros* Campbell & Clark, *Lithomelissa hoplites* Foreman, *Theocampe altamontensis* (Campbell & Clark), and *Stichomitra livermorensis* (Campbell & Clark), whereas the one from the Kobotobe Group is characterized by the occurrence of *Theocampe abschnitta* (Empson-Morin), *Dictyomitra lamellicostata* Foreman, and *Mylocercion acineton* Foreman.

Radiolarians from each sample occur in the same siliceous mudstone lithofacies, and the rock samples were carefully taken from non-folded, non-overtuned, and non-metamorphosed parts. Furthermore, in spite of varied states of preservation, each radiolarian assemblage has its own characteristic species, although the number of skeletons may differ. Thus, it is suggested that the differences in components between the two Late Cretaceous radiolarian assemblages may have been caused largely by oceanic environment. In this study, I attempt to distinguish the paleobiogeographic distributions of the seven characteristic species of the radiolarian faunas, and examine the differences in components and their possible causes from their worldwide distributions in Late Cretaceous time. The localities of radiolarians are illustrated in Figs 4, 5.

*Lithomelissa hoplites* (Fig. 2J) was reported from California (Foreman 1968), the mid-Atlantic Ocean (Foreman 1977), New Zealand (Hollis 1997), and Southwest Japan (Yamasaki 1987). *Lithomelissa heros* (Fig. 2I) was reported from California (Campbell & Clark 1944; Foreman

1968; Pessagno 1976), New Zealand (Hollis 1997), and the mid-Atlantic Ocean (Foreman 1978). *Lithomelissa* sp. were reported from the northeast coast of New Zealand (Ballance *et al.* 1989; Hollis 1997), Southwest Japan (Yamasaki 1987), and Hokkaido (Iwata & Tajika 1986). *Theocampe altamontensis* (Fig. 2K) was reported from the northeast coast of New Zealand (Ballance *et al.* 1989; Hollis 1997), the south Atlantic Ocean (Foreman 1977), the Antarctic Ocean (Ling & Lazarus 1990; Ling 1991), California (Campbell & Clark 1944), Southwest Japan (Muramatsu 1986; Yamasaki 1987), and the Bering Region (Vishnevskaya 1986). *Stichomitra livermorensis* (Fig. 2F) was reported from California (Campbell & Clark 1944; Foreman 1968), the Bering Region (Vishnevskaya 1986), the Antarctic Ocean (Ling 1991), New Zealand (Hollis 1997), Southwest Japan (Suyari 1986; Yamasaki 1987), and Hokkaido (Iwata & Tajika 1986, 1989). *Amphipyndax enesseffi* (Figs 2C, 3C) was reported from the mid-Pacific Ocean (Moore 1973; Empson-Morin 1981), California (Pessagno 1969), the mid-Atlantic Ocean (Foreman 1977, 1978; Empson-Morin 1984), Southwest Japan (Suyari & Hashimoto 1985; Muramatsu 1986; Suyari 1986; Yamasaki 1987), and Hokkaido (Iwata & Tajika 1989). The occurrence from Hokkaido (Iwata & Tajika 1989) is the northernmost limit of the range of *A. enesseffi* in the world. *Theocampe abschnitta* (Fig. 3I) was reported from the mid-Pacific Ocean (Empson-Morin 1981) and Southwest Japan (Muramatsu 1986; Yamasaki 1987). *Mylocercion acineton* (Fig. 3L) was reported from the mid-Pacific Ocean (Empson-Morin 1981), California (Foreman 1968), New Zealand (Hollis 1997), and the mid-Atlantic Ocean (Foreman 1978). *Dictyomitra lamellicostata* (Fig. 3H) was reported from the mid-Atlantic Ocean (Foreman 1977, 1978), California (Foreman 1968), New Zealand (Hollis 1997), and Southwest Japan (Suyari & Hashimoto 1985; Suyari 1986).

With respect to the relation between radiolarian distribution and latitude, *Amphipyndax enesseffi*, *Theocampe abschnitta*, *Mylocercion acineton*, and *Dictyomitra lamellicostata* were restricted to the low to intermediate latitudes except for New

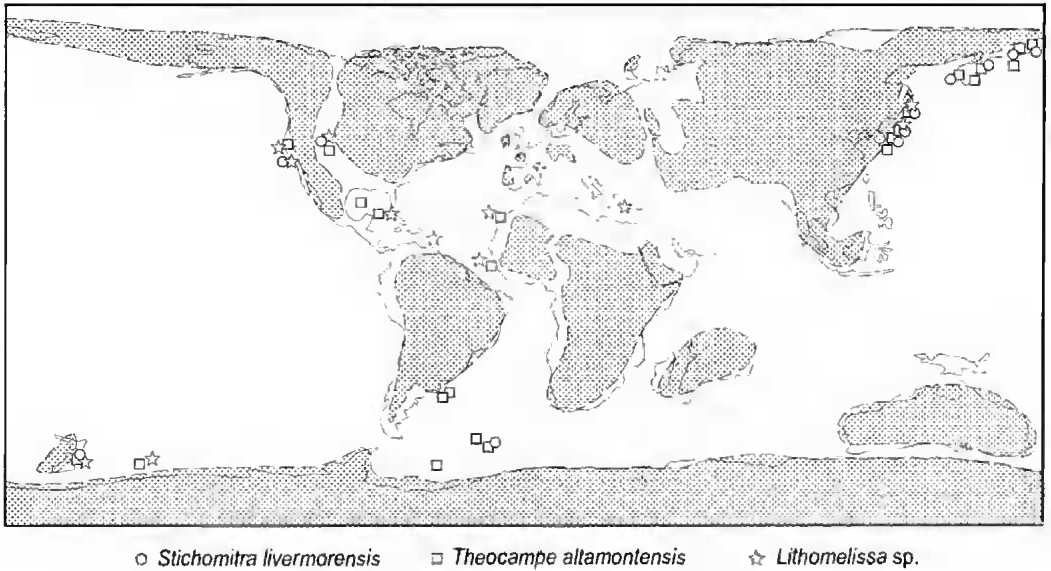


FIG. 4. — Distribution of *Stichomitra livermorensis* (Campbell & Clark), *Lithomelissa* sp. (including *L. heras* Campbell & Clark and *L. hoplites* Foreman), and *Theocampe altamontensis* (Campbell & Clark) in the late Campanian to early Maastrichtian. Data are from Campbell & Clark (1944), Foreman (1968, 1977), Pessagno (1976), Empson-Morin (1984), Muramatsu (1986), Iwata & Tajika (1986, 1989), Vishnevskaya (1986), Yamasaki (1987), Ballance *et al.* (1989), Ling & Lazarus (1990), Ling (1991), Hollis (1997), and present research. This map has been synthesized from Barron *et al.* (1981), Smith *et al.* (1994), and Roberts & Kirschbaum (1995).

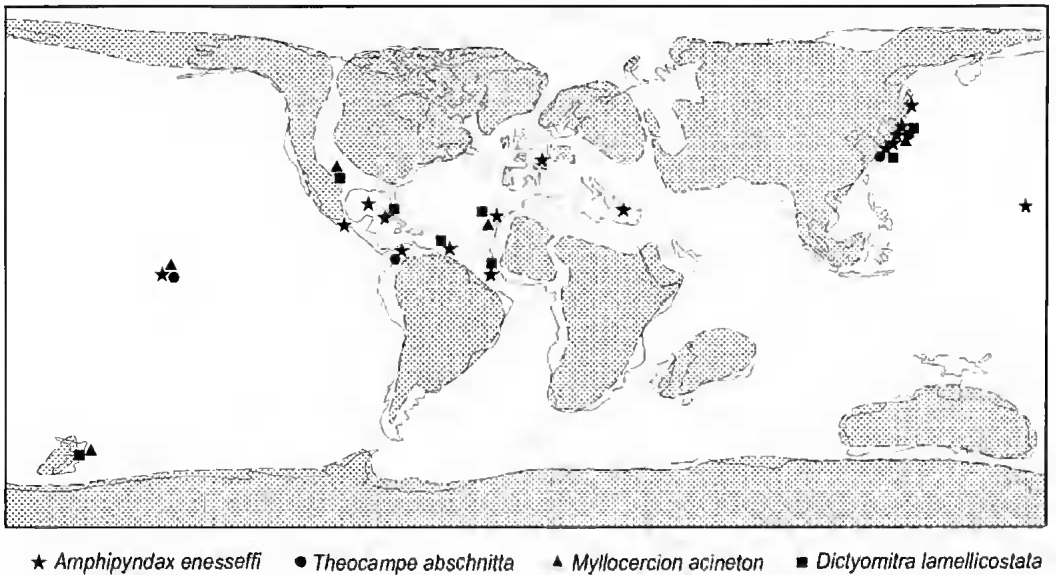


FIG. 5. — Distribution of *Amphipyndax enesseffi* Foreman, *Theocampe abschnitta* (Empson-Morin), *Myllocercion acineton* Foreman, and *Dictyomitra lamellicostata* Foreman in the late Campanian to early Maastrichtian. Data are from Pessagno (1969), Moore (1973), Empson-Morin (1981, 1984), Suyari & Hashimoto (1985), Muramatsu (1986), Suyari (1986), Yamasaki (1987), Iwata & Tajika (1989), Takahashi *et al.* (1989), Ishii *et al.* (1990), Hollis (1997), and present research.



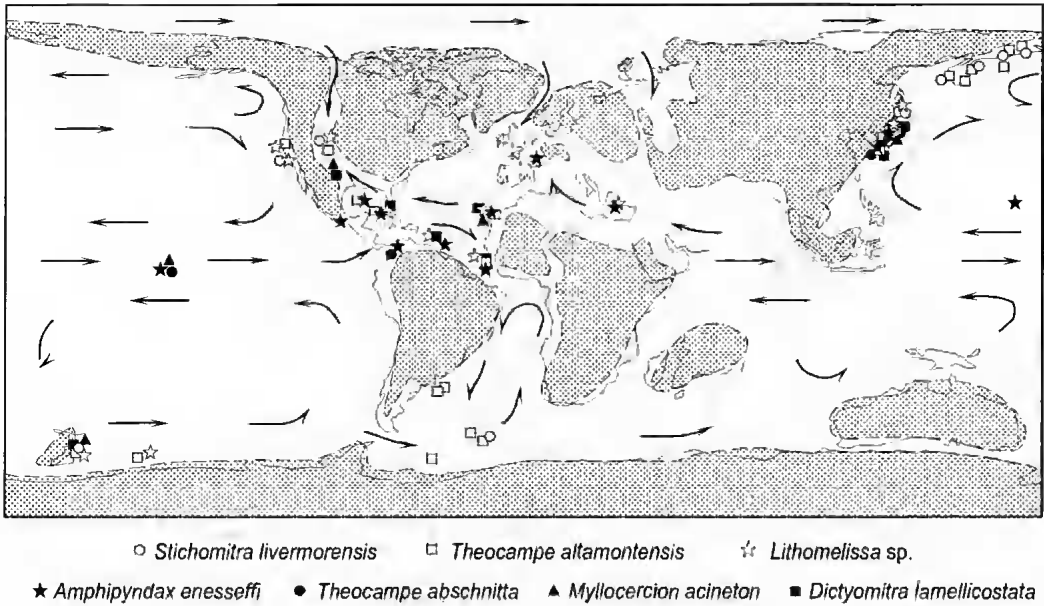


FIG. 6. — Relationship between Gordon's (1973) oceanic circulation and the global distribution of the seven characteristic radiolarian species. *Amphipyndax enesseffi*, *Theocampe abschnitta*, *Mylocercion acineton*, and *Dictyomitra lamellicostata* were restricted to the low to intermediate latitudes. *Lithomelissa heros*, *Lithomelissa hoplites*, *Theocampe altamontensis*, and *Stichomitra livermorensis* would tend to be cosmopolitan, however, only in the circum-Pacific region, they were apparently confined to northeastern Asia, northwestern North America, and the Antarctic. In the Tethys Sea and Atlantic Sea, there were more longitudinal channels which permitted mixing of their water with higher latitude water. Intermediate to high latitude radiolarians, therefore, reach much farther south to the Tethyan and central Atlantic regions along the seaways on the Laurasia. In contrast, circulation in the northern Pacific Ocean during the Late Cretaceous was dominated by a clockwise gyre. It made possibly contrasting distributions of radiolarians in this time.

Zealand (Hollis 1997). *Lithomelissa heros*, *Lithomelissa hoplites*, *Theocampe altamontensis*, and *Stichomitra livermorensis* would tend to be cosmopolitan. However, only in the circum-Pacific region, they were apparently confined to northeastern Asia, northwestern North America, and the Antarctic. That is, the paleobiogeographic distributions of the particular species of Late Cretaceous radiolarians seem to have reflected water-masses or their conditions.

Temperature is presumably a latitudinal component (e.g., Petrushevskaya 1971). Factors other than water depth and temperature such as nutrient levels and water chemistry undoubtedly controlled radiolarian distribution and abundance (e.g., Anderson 1983); many of these factors, however, are also related to water depth and temperature (Pessagno 1976). Among fossil organisms, the clearly latitudinal distribution of foraminifera in Cretaceous rocks indicates the importance of temperature (e.g., Caron 1985). Ammonoids also seem to be influenced by tem-

perature as they are separable into Tethyan (tropical) and Boreal assemblages (e.g., Obata & Matsukawa 1988). If the faunal distributions of radiolarians are due to differences in temperature of the water masses, the distribution is possibly influenced by the current systems. Not only do currents separate biogeographical regions, but the currents themselves contain characteristic radiolarian faunas.

Using analogies with the modern world and evidence of past climates, Gordon (1973) reconstructed global ocean currents for the Late Cretaceous. Fig. 6 shows the relationship between Gordon's (1973) oceanic circulation and the global distribution of the seven characteristic radiolarian species.

Any discussion of Late Cretaceous paleoenvironments first requires a description of land-sea distribution, which was significantly different from the present (Barron *et al.* 1981; Smith *et al.* 1994). Global marine transgression progressed during Late Cretaceous time (e.g., Payton 1977).

The Tethys Sea and the Atlantic Ocean were broad at this time, and there were more longitudinal channels (the northern Tethys and northern Atlantic longitudinal seaways) which permitted mixing of their water with higher latitude water, not necessarily at the surface of the water column. The circumpolar West Wind Drift would have caused cool currents to enter the North American mid-continental seaway and the European shelf seas (Gordon 1973). Intermediate to high latitude radiolarians, therefore, reach much farther south to the Tethyan and central Atlantic regions along the seaways on the Laurasia. It was proved by bimodal radiolarian faunas found at the Late Cretaceous Tethyan and mid-Atlantic regions, and was clearly associated with the Late Cretaceous transgressive phase. Pessagno & Blome (1986) referred to Gordon's model as being applicable to the Middle Jurassic world oceanic circulations. They also recognized the mixing of warm and cool water masses at the Tethyan and Atlantic regions in that time.

In contrast, circulation in the northern Pacific Ocean during the Late Cretaceous was dominated by a clockwise gyre (Gordon 1973), with a warm current (Paleo-Kuroshio Current) flowing north on its western margin where *Amphipyndax enesseffi*, *Theocampe abschnitta*, *Mylocercion acineton*, and *Dictyomitra lamellosata* thrived, and a cool current (Paleo-California Current) flowing south on the eastern margin where *Lithomelissa heros*, *Lithomelissa hoplites*, *Theocampe altamonensis*, and *Stichomitra livermorensis* were successful. Around the Japanese Islands, two oceanic currents may have existed: one from the northernmost Pacific Ocean and the other from the Equator. They crossed each other at the present position of the Japanese Islands.

#### Acknowledgements

I gratefully acknowledge the help of W. Kiessling and F. Cordey who read earlier drafts of this manuscript. I am indebted to H. Okada and A. Ishii for their invaluable contributions and criticism. Y. Ogawa and M. Marsukawa are thanked for their helpful discussions during the course of this study.

#### REFERENCES

- Amano M. & Marui N. 1958. — On the new species of *Spondylus* from the Cretaceous formation in Nagano Prefecture. *Journal of Science, Kumamoto University*, Series B 1: 27-31.
- Anderson O. R. 1983. — *Radiolaria*. Springer-Verlag, New York, 355 p.
- Ballance P. F., Barron J. A., Blome C. D., Bukry D., Cawood P. A., Chaproniere G. C. H., Frisch R., Herzer R. H., Nelson C. S., Quintero P., Ryan H., Scholl D. W., Stevenson A. J., Tappin D. G., & Vallier T. L. 1989. — Late Cretaceous pelagic sediments, volcanic ash and biotas from near the Louisville hot spot, Pacific Plate, palaeolatitude - 42°S. *Palaeogeography, Palaeoclimatology, Palaeoecology* 105: 111-124.
- Barron E. J., Harrison C. G. A., Sloan J. L., & Hay W. W. 1981. — Paleogeography, 180 million years ago to the present. *Eclogae geologicae helvetiae* 74: 443-470.
- Campbell A. S. & Clark B. L. 1944. — Radiolaria from Upper Cretaceous of Middle California. *Geological Society of America*, Special Paper 57: 1-61.
- Caron M. 1985. — Cretaceous planktic foraminifera: 17-86, in Bolli H. M., Saunders J. B. & Perch-Nielsen K. (eds), *Plankton Stratigraphy*. Cambridge University Press, Cambridge.
- Casey R. E. 1971. — Distribution of polycystine Radiolaria in the oceans in relation to physical and chemical conditions: 151-159, in Funnell B. M. & Riedel W. R. (eds), *The Micropalaeontology of Oceans*. Cambridge University Press, Cambridge.
- Empson-Morin K. M. 1981. — Campanian Radiolaria from DSDP site 313, mid-Pacific Mountains. *Micropalaeontology* 27: 249-292.
- 1984. — Depth and latitude distribution of Radiolaria in Campanian (Late Cretaceous) tropical and subtropical oceans. *Micropalaeontology* 30: 87-115.
- Foreman H. P. 1968. — Upper Maestrichtian Radiolaria of California. *Palaeontological Association, London*, Special Paper 3: iv + 1-82.
- 1977. — Mesozoic Radiolaria from the Atlantic Basin and its borderlands: 305-320, in Swain F. M. (ed.), *Stratigraphic Micropalaeontology of Atlantic Basin and Borderlands*. Elsevier, Amsterdam.
- 1978. — Mesozoic Radiolaria in the Atlantic Ocean off the northwest coast of Africa, Deep Sea Drilling Project, Leg 41: 739-761, in Lancelot Y., Seibold E. et al. (eds), *Initial Reports of the Deep Sea Drilling Project* 41. U. S. Government Printing Office, Washington D. C.
- Goll R. M. & Björklund K. R. 1971. — Radiolaria in surface sediments of the North Atlantic Ocean. *Micropalaeontology* 17: 434-457.
- Gordon W. A. 1973. — Marine life and ocean surface currents in the Cretaceous. *Journal of Geology* 81: 269-284.

- Haeckel E. 1887. — Report on the Radiolaria collected by H.M.S. *Challenger* during the years 1873-1876. *Report on the Scientific Results of the Voyage of the H.M.S. Challenger, Zoology* 18, clxxxviii + 1803 p.
- Hollis C. J. 1997. — Cretaceous-Paleocene Radiolaria from eastern Marlborough, New Zealand. *Institute of Geological & Nuclear Sciences monograph* 17, 152 p.
- Ishii A. & Takahashi O. 1993. — Accretion complexes and related forearc basins in the Cretaceous of central Japan, with special reference to the continuity of accretion tectonism and associated metamorphism. *Palaeogeography, Palaeoclimatology, Palaeoecology* 105: 111-124.
- Ishii A., Takahashi O. & Hayashi N. 1990. — Geology of the Kawakami-Sudama area, western part of the Kanto Mountains, central Japan. *Bulletin of Tokyo Gakugei University, Section 4*, 42: 171-181 [in Japanese with English abstract].
- Iwata K. & Tajika J. 1986. — Late Cretaceous radiolarians of the Yubetsu Group, Tokoro Belt, northeast Hokkaido. *Journal of the Faculty of Science, Hokkaido University, Series IV*, 21: 619-644.
- 1989. — Jurassic and Cretaceous radiolarians from the pre-Tertiary system in the Hidaka Belt, Maruseppu region, northeast Hokkaido. *Journal of the Faculty of Science, Hokkaido University, Series IV*, 22: 453-466.
- Ling H. Y. 1991. — Cretaceous (Maestrichtian) radiolarians: Leg 114: 317-324, in Ciesielski P. F., Kristoffersen Y. et al. (eds), *Proceedings of the Ocean Drilling Program, Scientific Results 114*. College Station, TX (Ocean Drilling Program).
- Ling H. Y. & Lazarus D. B. 1990. — Cretaceous radiolaria from the Weddell Sea: Leg 113 of the Ocean Drilling Program: 353-363, in Barker P. F., Kennett J. P. et al. (eds), *Proceedings of the Ocean Drilling Program, Scientific Results 113*. College Station, TX (Ocean Drilling Program).
- Makino Y. 1973. — Stratigraphical and sedimentological studies of the Kobotoke Group, Kawanto Mountainland, central Japan. *Journal of the Geological Society of Japan* 79: 299-308 [in Japanese with English abstract].
- Moore T. C. 1973. — Radiolaria from Leg 17 of the Deep Sea Drilling Project: 797-869, in Winterer E. L., Ewing J. et al. (eds), *Initial Reports of the Deep Sea Drilling Project 17*. U. S. Government Printing Office, Washington D. C.
- Muramatsu T. 1986. — Late Cretaceous-earliest Paleogene? radiolarians from the Shimanto Belt (Northern Belt) in the southern part of the Akaishi Mountains, central Japan. *Journal of the Geological Society of Japan* 92: 311-313 [in Japanese].
- Obata I. & Matsukawa M. 1988. — Some Boreal or Subboreal Ammonites in the Japanese Barremian: 469-476, in Wiedmann J. & Kullmann J. (eds), *Cephalopods - Present and Past*. Schweizerbart'sche Verlagsbuchhandlung, Stuttgart.
- Payton C. E. (ed.) 1977. — Seismic Stratigraphy - applications to hydrocarbon exploration. *American Association of Petroleum Geologists, Memoir* 26, 516 p.
- Pessagno E. A. 1969. — Upper Cretaceous Stratigraphy of the Western Gulf Coast Area of Mexico, Texas, and Arkansas. *Geological Society of America, Memoir* 111, 139 p.
- 1976. — Radiolarian zonation and stratigraphy of the Upper Cretaceous portion of the Great Valley sequence, California Coast Ranges. *Micro-paleontology*, Special Publication 2: 1-95.
- Pessagno E. A. & Blome C. D. 1986. — Faunal affinities and tectonogenesis of Mesozoic rocks in the Blue Mountains province of eastern Oregon and western Idaho, in Vallier T. L. & Brooks H. C. (eds), *Geology of the Blue Mountains region of Oregon, Idaho and Washington*, U. S. Geological Survey Professional Paper 1435: 65-78.
- Petrushevskaya M. G. 1971. — Radiolaria in the plankton and recent sediments from the Indian Ocean and Antarctic: 319-329, in Funnell B. M. & Riedel W. R. (eds), *The Micropaleontology of Oceans*. Cambridge University Press, Cambridge.
- Roberts L. N. R. & Kirschbaum M. A. 1995. — Paleogeography of the Late Cretaceous of the western interior of middle North America - coal distribution and sediment accumulation. U. S. Geological Survey Professional Paper 1561, 115 p.
- Sakai A. 1987. — *Geology of the Tsukaichi District*. With Geological Sheet Map at 1:50,000. Geological Survey of Japan, Tsukuba, 75 p. [in Japanese with English abstract].
- Sanfilippo A. & Riedel W. R. 1985. — Cretaceous radiolaria: 573-630, in Bolli H. M., Saunders J. B., and Perch-Nielsen K. (eds), *Plankton Stratigraphy*. Cambridge University Press, Cambridge.
- Smith A. G., Smith D. G., & Funnell B. M. 1994. — *Atlas of Mesozoic and Cenozoic coastlines*. Cambridge University Press, Cambridge, 99 p.
- Suyari K. 1986. — Restudy of the Northern Shimanto Subbelt in Eastern Shikoku. *Journal of Science College of General Education, University of Tokushima* 19: 45-54 [in Japanese with English abstract].
- Suyari K. & Hashimoto H. 1985. — A radiolarian assemblage from the Izumi Group of eastern Shikoku. *Journal of Science College of General Education, University of Tokushima* 18: 103-127 [in Japanese with English abstract].
- Takahashi O. & Ishii A. 1993. — Paleo-oceanic environment in the Late Cretaceous time, inferred from radiolarian fauna of *Amphipyndax tylotus* zone, in Sakai T. & Aita Y. (eds), *Proceedings of the Forth Radiolarian Symposium, News of Osaka Micropaleontologists*, Special Volume 8: 261-270 [in Japanese with English abstract].
- Takahashi O., Hayashi N. & Ishii A. 1989. — Radiolarian fossils from the Masutomi Group, sou-

- thwestern part of the Kanto Mountains, central Japan, and their significance. *Journal of the Geological Society of Japan* 95: 953-955 [in Japanese].
- Taketani Y. 1982. — Cretaceous radiolarian biostratigraphy of the Urakawa and Obira areas, Hokkaido. *Science Reports of the Tohoku University, 2nd Series (Geology)* 52: 1-76.
- Vishnevskaya V. S. 1986. — Middle to Late Cretaceous radiolarian zonation of the Bering region, U.S.S.R. *Marine Micropaleontology* 11: 139-149.
- Watanabe K. 1958. — Shoya Formation: 95-96 [in Japanese], in Fujimoto H. (ed.), *Geologic History of the Minami-saku-gun District*. Minami-saku Kyoiku-kai, Nagano.
- Yamasaki T. 1987. — Radiolarian assemblages of the Izumi Group in Shikoku and western Awaji Island, Southwest Japan. *Journal of the Geological Society of Japan* 93: 403-417 [in Japanese with English abstract].

*Submitted for publication on 29 January 1998;  
accepted on 24 July 1998.*

## APPENDIX

### SAMPLE LOCALITIES

Figured specimens will be deposited in the Tokyo Gakugei University. The following sample numbers, Sh and St, refer to samples from the Shoya Formation and the Kobotoke Group, respectively. For St-1, see Loc. 8 in Takahashi *et al.* 1989; Loc. 12 in Ishii *et al.* 1990.

Samples	Geologic setting	localities
Sh-1	Siliceous dark gray mudstone	36°13'07"N, 138°35'04"E
Sh-2	Siliceous dark gray mudstone	36°13'07"N, 138°35'04"E
Sh-3	Siliceous dark gray mudstone	36°13'07"N, 138°35'04"E
Sh-4	Siliceous dark gray mudstone	36°12'51"N, 138°35'04"E
Sh-5	Siliceous dark gray mudstone	36°12'51"N, 138°35'04"E
St-1	Siliceous dark gray mudstone	35°53'39"N, 138°31'10"E
St-2	Siliceous black mudstone	35°46'06"N, 138°54'33"E